People-Centric Systems Reliability Teaching Methodology at The University of Tennessee, Knoxville

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Abstract

Instruction in Systems Thinking and Design at the undergraduate and graduate level has strongly emphasized that systems performance is dependent upon efficiency. However, in most cases, efficiency as the sole target provides results that do not represent the state of a system in its entirety. In response to these issues, members of the Center for Advanced Systems Research (CASRE), at The University of Tennessee, Knoxville have developed methods to teach systems thinking through the concept of reliability. Changing the paradigm from efficiency to reliability in both the undergraduate and graduate-level courses on Reliability Engineering has demonstrably improved the students' understanding of systems analysis. Instead of the efficiency-based system analysis, it is possible to dive deeper and evaluate systems' behavior with respect to their intended function over specified periods of time. This approach enables the analysis of each system component, breakdown of the component's failure modes, elaboration of the system as a collection of networks, and the role of people within systems. The result is the establishment of reliability-based performance metrics, to identify and mitigate variations and disruptions within systems. The next phase comprises a hands-on experience, where students perform a reliability analysis of chosen systems at their companies. These analyses support the development of reliability-based solutions for systems and sustainability plan to enhance the employees' quality of life. The combination of a strong curriculum in systems thinking and engineering, along with people-centric reliability, has yielded several solutions for organizational issues.

Keywords

Systems Thinking. Systems Performance. People-Centric Reliability. Reliability Engineering.

People-Centric Reliability Model

The core domain of the teaching methods presented in this paper is people-centric operational excellence. "Operational excellence" is the design and implementation of organization-wide practices that improve its outcomes [1-3]. Lean Manufacturing, Lean Enterprise, or simply Lean, is the most popular operational excellence model that is widely adopted for university instruction in business and engineering courses. Over several years of undergraduate and graduate instruction, scholarship, and applied research in operational excellence at the University of Tennessee, Knoxville (UT), Dr. Rupy Sawhney noticed that implementations of Lean were not yielding the sustainable expected results in the long haul. The evaluation of a system through a static mechanism such as Lean Enterprise, where the reduction of waste is the main point, does not necessarily represent the best solution for the overall process or system [4, 5]. In some cases, the implementation of Lean would in fact worsen system behavior in terms of variations and disruptions. The long-term effect of these challenges and uncertainties is to negatively affect employee quality of life.

The Sawhney Model is a people-centric, reliability-based approach that addresses the key objective of sustainable operational excellence. Its formulation leverages subject matter expertise in Systems Thinking and Reliability Engineering [6, 7]. It has a practical and dynamic outlook to simplify its adaptability to multiple environments (e.g., manufacturing, healthcare, government, and supply chain). The broad steps in the model include four modules: problem identification, design of performance measurement systems that align productivity with organizational outcomes, design of solutions, and instituting a sustainability plan to maintain the solution effective. Figure 1 exhibits the dynamics of the four modules.

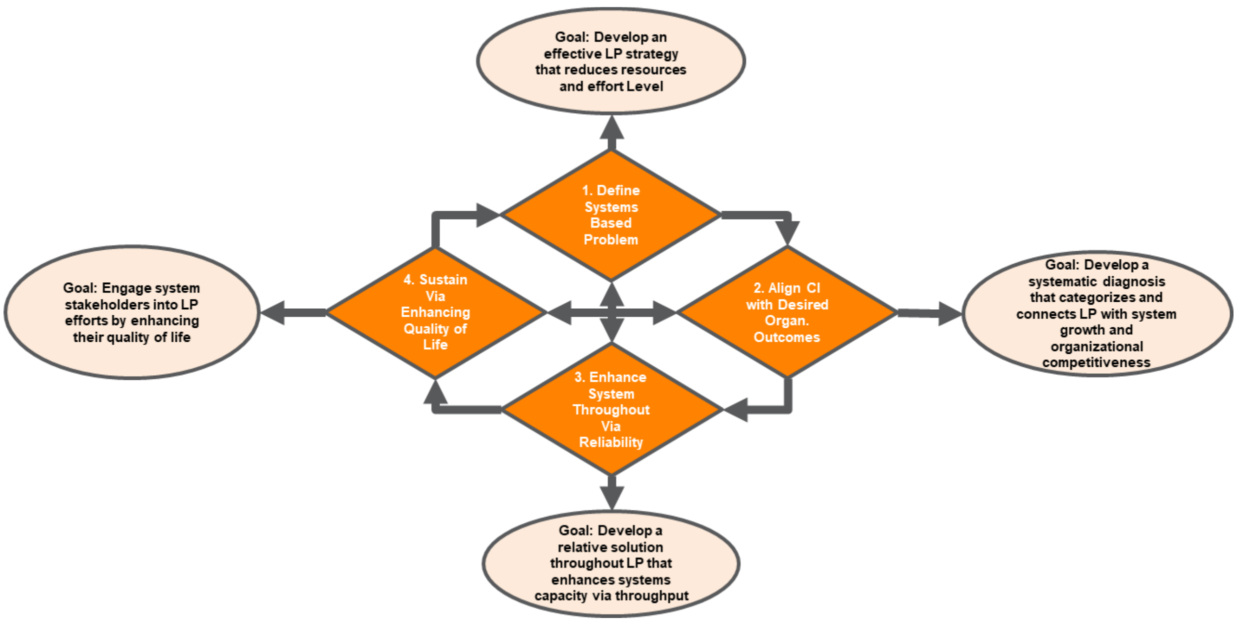

Figure 1 - Overview of The Sawhney Model. Adapted from source [6]

Module 1 comprises the procedure for problem identification in an organization, utilizing tools that allow practitioners to understand the system or process in depth. The business function that constrains the system (e.g., department, sector, line, etc.) is identified. This systems-based perspective provides the background to construct a Value Stream Map (VSM) of the business constraint. VSM is a well-known method in industrial engineering to describe the relationships between the process steps in terms of time and volume demands at each step. The Key-Value Stream is extracted from the VSM to understand the most critical process issues. The process is classified based on its level of variation. This serves as a background for the initial optimization strategy based on variation, disruption, or flow.

Module 2 understand**s** the metrics that align system performance improvements with the organizational outcomes. A performance measurement system categorizes the metrics in levels that allow a deeper understanding of system behavior (see Figure 2). Each set of metrics is described as **leading** or **lagging** indicators. Leading indicators are the metrics that generate impact on the system, whereas lagging indicators are the impacted metrics.

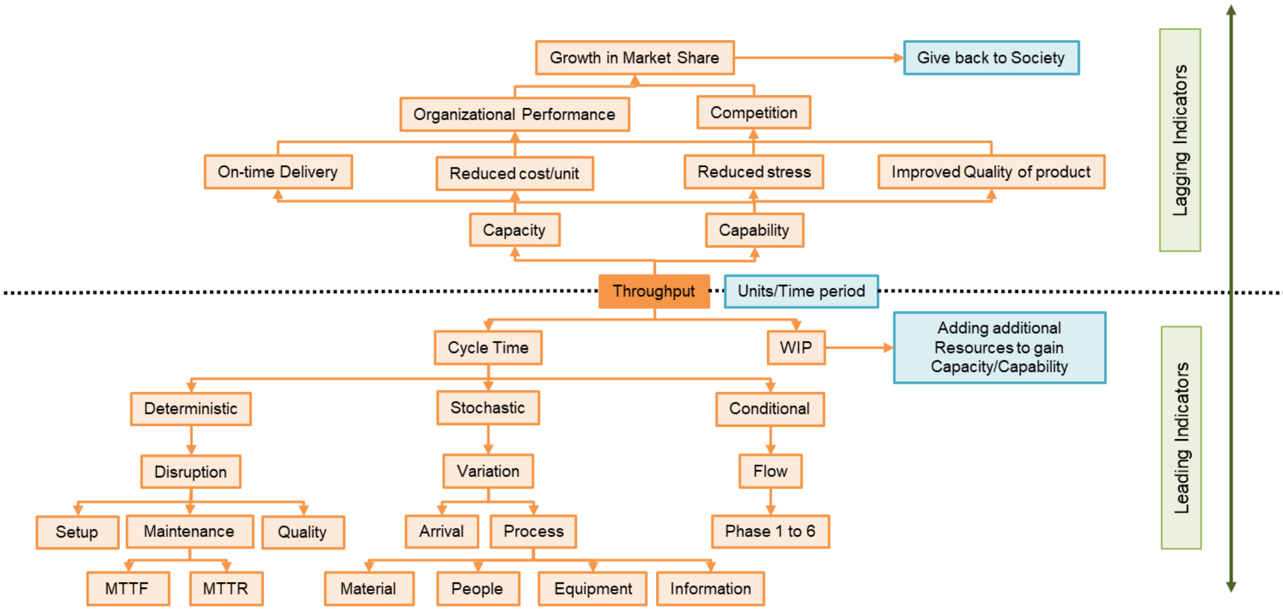

Figure 2 – Performance Measurement System (PMS) that aligns productivity with organizational outcomes and employee quality of life

Module 3 optimizes system performance by designing solutions that bridge the leading and lagging indicators. The connecting concept is Throughput (TH) which is defined by Little's Law [8] as the ratio between work-in-progress (WIP) and cycle time (CT). Throughput is a function of multiple factors that determine business sustainability, including on-time delivery, reduced cost/unit, reduced stress levels in the employees, and improved quality of the product. The throughput is optimized using concepts of reliability engineering. According to [7], reliability is the ability of a process to perform its intended function under predefined environmental conditions over a specific period of time. The analysis of successful performance is performed using failure modes, categorized into People, Equipment, Material, and Information (PMEI). The failure modes correspond to any conditions that may affect system components to compromise overall system performance. The solution for the constraining business function targets improving system reliability that mitigates the system's failure modes.

Module 4 sustains the solution long-term by developing a strategy to prevent the system from going back to its original state. The strategy is centered in maintaining the solution in place through identifying the factors that affect people's quality of life. This includes interventions based on improved training that is cognizant of workplace stressors and modification of work based on the nuances of organizational, regional, and national culture. Developing a strategy that improves engagement and peer-to-peer accountability promotes a sense of belonging in a workplace and sustains employee contributions to organizational performance.

Shifting the Paradigm of Systems Design

Instruction in operational excellence for courses offered by undergraduate, graduate, and certificate programs in Industrial and Systems Engineering at UT has undergone a paradigm shift based on the Sawhney Model. Students are encouraged to approach operational excellence based on novel questions compared to typical instruction, primarily: Which solution is more effective to optimize systems, while enhancing employee quality of life, efficiency or reliability? Students learn to evaluate "effective" system functioning in terms of system reliability, instead of the output to input ratios employed by the commonly used efficiency-based system evaluation. Reliability, as a metric for People, Material, Equipment, and Information, becomes a focus point for instructors at UT when guiding students towards designing system solutions.

Furthermore, the instructional methodology for courses is supplemented by a conscious effort to maintain an open and interactive environment in the class. This step is critical towards the objective of disseminating advanced concepts in systems design and reliability. Students are given freedom to explain experiences related to their work environments, while the instructors promote a space for critical thinking related to why, how, and what to do to seek people-centric operational excellence. As appropriate for the course level and materials, project-based learning principles [9] are applied to the course design to allow students to explore real-world challenges to enhance their understanding of operational excellence in practice.

Undergraduate Coursework on People-Centric Reliability-based Operational Excellence

The undergraduate curriculum for operational excellence in Industrial Engineering (IE) at UT has been modeled with two objectives: 1. To provide undergraduate students with the know-how for systems thinking and reliability, and 2. To equip them with the tools to practice the knowledge.

i. EF 203 – Engineering-based Problem Solving

Undergraduate majors in Industrial and Systems Engineering and the College of Business, for both honors and regular programs, are required to take EF 203 – Engineering-based Problem Solving. This course provides an overview of problem-solving techniques and requirements planning. The course is designed with the intention of highlighting early career challenges to students and equipping them with the engineering tools that may help address some of the challenges. Examples of tools include Performance Measurement Systems, Failure Modes & Effects Analysis, Compassionate Leadership, Requirements Planning, and Introduction to Systems Thinking. Students are divided into project groups to apply the Sawhney Model to real-world problems faced by industry partners. The course has active industry participation from local partners in East Tennessee. As a project outcome, industry and faculty evaluators assess the enhancement in critical thinking presented by the students before and after project completion. Specifically, students are assessed for their development of a reliability-based systems design that results in a stable and resilient system.

ii. IE 427 – Lean Production Systems

The senior level undergraduate course, IE 427 – Lean Production Systems, provides a deeper approach to enhance system productivity and project management skills. The course provides students with know-how both in the Sawhney Model and classic Industrial Engineering theory (e.g., Scheduling, Toyota Production System, Phases of Lean, Ergonomics, and Mistake Proofing). The objective of the course is to equip students with the ability to strategize, develop and implement systems in a manner that ensures value to the organization, customer, and the employees. In other words, students must be prepared to be leaders that have operational excellence skills that impact society. A student's progress is evaluated both in terms of direct design of systems and the ability to mentor others in creating effective systems. The instructor evaluation for students includes: 1. Student awareness of their important role and obligations to society, 2. Student ability to develop alternative approaches for system changes, 3. Student ability to understand basic lean and flow concept, and 4. Student critical problem-solving development.

Graduate Coursework on People-Centric Reliability-based Operational Excellence

Graduate-level courses in Industrial and Systems Engineering at UT provide regular and nontraditional students (for example, working individuals seeking a graduate degree) with the opportunities to becoming experts in systems design and thinking based on people-centric and reliability analysis. The onsite Master's program in Industrial and Systems Engineering, also called the Cohort Program, provides nontraditional students with the opportunity to go back to the classroom to learn engineering tools that will benefit their employers and professional environments. The coursework is completely focused on people-centric reliability-based operational excellence, where the students present a capstone project to their committee, as well as their employers. The Cohort Program has been designed in partnership with the US Department of Energy (DOE) to attend to the needs for performance enhancement in DOE sites through reliability engineering, while enhancing the employees' quality of life. The coursework for such program comprises fundamentals of statistics, advanced production and inventory control, linear optimization, as well as the following people-centric reliability-based courses.

i. IE 516 – Reliability of Lean Systems

The course provides an in-depth understanding of the basic Lean principles and reliability (ReLEANability) concepts as they apply to both the manufacturing and service sectors. Topics such as performance measurement, role of flow, role of variation, role of disruption, relationship between flow, variation, disruption, and reliability are covered. The objective of the course is to provide students with the know-how to apply reliability principles to processes design and professional research. The course highlights the critical role that the Lean expert plays and the impact of their decisions on customers, employees, and society. Students are required to illustrate their ability to integrate Lean and reliability in an actual business environment. The mechanism for this is a semester-long team project involving an enterprise-level evaluation of the company's current equipment reliability, human reliability, supply chain reliability, or the reliability of the Lean system as a whole. Students are evaluated for their ability to apply many of the concepts discussed in this course to the project. Students are required to deliver a graduate-level project report that recommends actions to transition an organization into a "Reliable Lean" enterprise.

ii. IE 527 – Lean Production Systems

The course provides participants with the strategies for planning, development, and implementation of operational excellence strategies using the framework of the Sawhney Model. Students are provided with know-how for the Toyota Production System, including traditional

Lean tools, techniques, and methodologies that may supplement this process. The system improvements must integrate people, technology, processes, and information dimensions using the principles of Factory Physics, which presents mathematical and engineering principles behind several operational excellence concepts. Students are required to present the analysis of principles from the perspective of Little's Law, Queuing Theory, Flow (Push, Kanban & CONWIP systems), and Variation. Students are evaluated for their ability to present a logical approach to consolidate system elements through the lens of "manufacturing science", as presented in these techniques.

iii. IE 691 – Systems Resilience for Operational Excellence

IE 691 – Systems Resilience for Operational Excellence is a Ph.D. level course in which graduate students are challenged to develop strategies for systems resilience through reliability. The course provides an in-depth understanding of the reliability and resilience concepts as applied to various domains. The role and importance of people in resilience is discussed. Students are required to perform a literature review of resilience. Resilience is related to flow, variation, and disruption of systems. Reliability is placed as a crucial item in the analysis of systems resilience, to provide students with tools that enhance the visualization and controllability of systems. Resilience-based performance measurement systems are evaluated. Unstructured reliability platform is utilized in developing a resilience platform. Students are evaluated on the ability to present a resilience strategy for their research, with supporting arguments for the inclusion of specific techniques in the strategy, including advanced simulation modeling, network optimization, and machine learning.

Table 1: Student evaluation of courses presented in this paper

Rubric	EF 203 (Fall 2020)	IE 427 (Spring 2020)	IE 516 (Fall 2019)	IE 527 (Fall 2019)	IE 691 (Summer 2021)
"Course challenged you to learn something new"	5	4.56	4	4.33	5
"Class was well-organized"	4.69	4.19	4	4	4.67
"Course materials enhanced your learning"	4.58	4.19	4	3	5

Conclusions

Table 1 shows the outcomes of the project based on recent course evaluations. The outcomes are perceived by students in three key areas identified in the teaching methodology: 1. The ability of the new material to challenge students to learn better, 2. The organization provided by instructors in supporting the material, and 3. The ability of the course structure and material to enhance learning. The scores (scale of 5) provide clear indication that the student experience supports instructional objectives.

In summary, this paper highlights the teaching focus in operational excellence for Industrial and Systems Engineering courses at UT. The courses highlighted in this paper have resulted in direct and indirect benefits to collaborative industry projects, educational programs, as well as research initiatives. By shifting the paradigm to reliability-based operational excellence, students have gained a more holistic perspective towards systems thinking and design. The materials developed in these courses benefit undergraduate as well as graduate levels of instruction.

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